Attachment D

2017 CORRECTIVE ACTION PROGRAM PLAN

Effective: ______, 2017

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Acronyms and Abbreviations

~	approximately
µg/L	micrograms per liter
AAC	Alaska Administrative Code
ADEC	Alaska Department of Environmental Conservation
ADNR	Alaska Department of Natural Resources
APDES	Alaska Pollutant Discharge Elimination System
AS	air sparge
BTEX	benzene, toluene, ethylbenzene, xylenes
CAMP	corrective action modification plan
CAPP	corrective action program plan
CM	corrective measure
COC	contaminant of concern
COPC	contaminant of potential concern
DRO	diesel-range organics
EPA	U.S. Environmental Protection Agency
GAC	granular activate carbon
gpm	gallons per minute
GRO	gasoline-range organics
KSI	Kent & Sullivan, Inc.
LNAPL	light, non-aqueous phase liquid
LNG	liquid natural gas
MCL	maximum contaminant level
MNA	monitored natural attenuation
MTBE	methyl-tert-butyl ether
NA	natural attenuation
OSW	Office of Solid Waste
Permit	Tesoro's RCRA Part B Post Closure Permit
Phillips	ConocoPhillips
PRM	Philips Remedial Measure
PM	Phillips-Marathon
PRG	preliminary remediation goal (EPA Region 9)
QPR	quarterly progress report
RBC	risk-based concentration (EPA Region 3)
RCRA	Resource Conservation and Recovery Act
RTO	regenerative thermal oxidizer
scfm	standard cubic feet per minute
SI	surface impoundment
TCE	trichloroethene
Tesoro	Tesoro Alaska Company

Acronyms and Abbreviations (cont'd)

TGPS	target groundwater protection standard
Trihydro	Trihydro Corporation
TWUP	temporary water use permit
UCA	upper confined aquifer

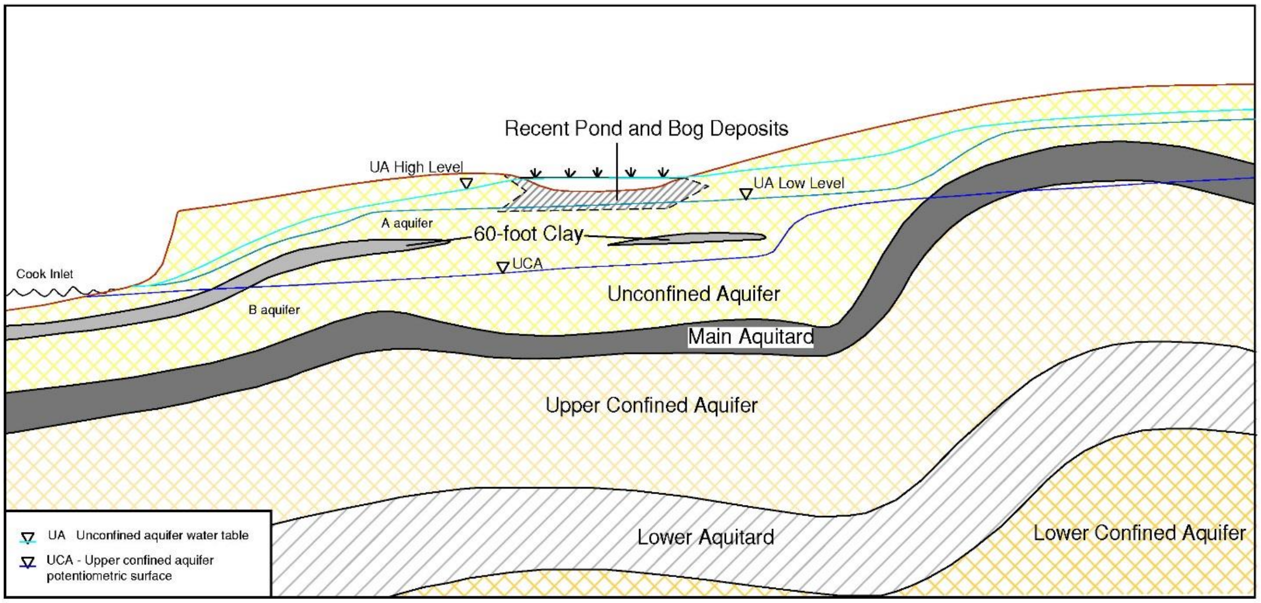
D-1.0 INTRODUCTION

This document describes the 2017 Corrective Action Program Plan (2017 CAPP) for the Tesoro Alaska Company (Tesoro) refinery (site) located in Nikiski, Alaska (Figure D-1) which is being implemented pursuant to Tesoro's Resource Conservation and Recovery Act (RCRA) Post-Closure Part B Permit (Permit). The CAPP is intended to replace the 2007 *Corrective Action Program Plan* (Kent & Sullivan, Inc (KSI), 2001b) (2007 CAPP). The 2017 CAPP updates the 2007 CAPP by providing additional corrective measures and monitoring plans based on investigations and feasibility studies performed since 2007 and incorporating improvements to the active remedial systems This document is current as of its publication date, and Tesoro will document significant changes to the designations, descriptions, or interpretations contained herein by reporting them in future Quarterly Progress Reports (QPRs) and by providing revised Permit tables and figures as appropriate. The 2017 CAPP was prepared by Trihydro Corporation (Trihydro) for Tesoro.

D-1.1 SITE CONCEPTUAL MODEL

The Tesoro refinery project area borders Cook Inlet in the Kenai Lowland physiographic province. Karlstrom (1964) describes five major Pleistocene glaciations that occurred in the Kenai Lowland. The glaciations shaped the present topography, and the shallow sedimentary sequences underlying the area were deposited in environments dominated by glacial processes. According to Karlstrom, the refinery area is situated near the middle of the Pleistocene depositional basin, and a persistent glacial lake in this area received sediments from the Alaska Range to the west and the Kenai Mountains to the east. Stratified sand and gravel were deposited in proglacial fluvial and fluvial-delta environments during low lake level periods, and silt and clay were deposited on the lake bottom during high water periods. Nelson (1981) estimates the sequence to be at least 500 feet thick in the Nikiski industrial area. The sedimentary deposits crop out along the Cook Inlet bluff and are present at the surface or beneath a thin loess mantel over most of the refinery area.

The regional groundwater system in the refinery area occurs in the Pleistocene sedimentary sequence and consists of an unconfined aquifer and upper and lower confined aquifers separated by regionally extensive silt and clay aquitards (Nelson, 1981). Investigations in the refinery area have provided additional details of the local groundwater system. The following sections summarize the stratigraphy, structure, and hydrogeology of the refinery project area based on the results of the Phillips Remedial Measure (PRM)-area investigations (KSI, 1997 and 1999a), the E-77 area investigation (KSI, 1999b), the upper confined aquifer (UCA) investigations (KSI, 2000), the B-aquifer investigation (KSI, 2001a), and the E-228 corrective action modification plan investigation (KSI, 2002).



Diagrammatic cross section of the refinery area illustrating the topography and hydrostratigraphy of the site. Not to scale.

D-1.1.1 Hydrostratigraphy

The diagram above illustrates the hydrostratigraphic model of the refinery area, and the following paragraphs describe the principal stratigraphic units.

1) Recent *pond and bog deposits* occur at the surface in low-lying areas and are composed primarily of peat, organic silt, and diatomaceous earth beds. Surface water and shallow groundwater is frequently perched on the unit, but this water is not hydraulically connected to the underlying unconfined aquifer.

2) The unconfined aquifer consists primarily of stratified, well-graded, medium to coarse sand with gravel interbedded with smaller amounts of poorly-graded, fine to medium sand and silty sand. Laterally discontinuous clay and silt beds were deposited in one to as many as three horizons within the stratified sand and gravel sequence. The principal fine-grained unit in the PRM area is referred to as the 60-foot clay (KSI, 1997) which is thought to correlate to the most widely occurring fine-grained unit in the Phillips-Marathon (PM) area. The unconfined aquifer inland from the Cook Inlet beach is generally 60 to 90 feet thick (combined saturated and unsaturated zones), but significantly thicker and thinner zones occur locally.

   Groundwater in the unconfined aquifer is divided into three sub-units depending on its relationship to the 60-foot clay. *Merged* portions of the unconfined aquifer occur where the fine-grained unit is absent, the *A-aquifer* refers to groundwater above the 60-foot clay, and the *B-aquifer* refers to groundwater below the 60-foot clay. As implied in the name, groundwater typically occurs under unconfined conditions in the merged and A-aquifer sub-units, but the B-aquifer is generally confined.

The merged portion of the aquifer is locally confined beneath some areas where the recent pond and bog deposits occur.

3) The *main aquitard* is a laterally continuous fine-grained unit averaging approximately 18 feet thick separating the unconfined aquifer from the upper confined aquifer (UCA). It is characterized by very stiff to hard, massive clay often containing matrix-supported fine gravel, but silt, interbedded silt and fine sand, and poorly graded sand layers also occur in the unit.

4) The *UCA* is a regionally extensive sand and gravel unit approximately 90 to 130 feet thick. The lithology is similar to the unconfined aquifer and consists predominantly of well-graded, fine to coarse sand with fine to coarse gravel and subordinate silty sand. Groundwater occurs under confined conditions in most of the aquifer, but is locally unconfined in areas where the main aquitard is structurally high.

5) The *lower aquitard* is a regionally extensive sequence of clay interbedded with gravel and sand deposits approximately 75 to 90 feet thick. The lower aquitard forms the base of the groundwater system impacted by releases from the Tesoro refinery.

6) The *lower confined aquifer* is a regionally extensive but poorly defined unit; only two wells in the refinery area penetrate the unit. The logs for those wells describe it as predominantly gravel and silty sand.

D-1.1.2 Structure

The proglacial lakebed deposits are significantly deformed by folding and faulting in the refinery area. The deformation is apparently unusual in the Kenai Lowland based on Karlstrom's (1964) observation that these deposits generally show only localized deformation associated with processes such as differential compaction, subaqueous slumping, and iceberg dragging. The origin of the deformation in the refinery area is not known but may be associated with large-scale subaqueous slumping or deposition adjacent to or above a large (hundreds of acres) melting ice block. The deformation pattern does not appear to reflect a uniform stress regime and is, therefore, not consistent with deep-seated regional tectonism, although this origin cannot be ruled out based on existing information.

The deformation in the refinery area is characterized by northeast-trending high-angle faults and irregularly-oriented open folds and flexures that create more than 100 feet of structural relief on the main aquitard. The 60-foot clay is typically less deformed than the older deposits, and faults exposed on the Cook Inlet bluff die out in the upper part of the unconfined aquifer indicating that deformation was ongoing and ceased during deposition of the unconfined aquifer.

Structural interpretations in the refinery area are uncertain because of the irregular orientation of folds and flexures, the relatively small number of deep boreholes, and other factors. Recognizing that the uncertainties may allow alternative explanations, the principal structural features (as defined by the top of the main aquitard) in the current site conceptual model are: 1) a northeast-trending graben (trough) in the PRM area bounded by high-angle faults referred to as the north and south faults, 2) the northeastward continuation of this trough into the eastern portion of the refinery as a combined syncline and half-graben along the south fault, 3) a broad, dome-shaped structural high centered below the refinery process units and extending into the SI area, and 4) a deep synclinal trough located on the west side of the process area structural high. The south fault appears to die out immediately east or southeast of the process unit area. The strike of the north fault follows an arcuate trend that curves to the north inland from Cook Inlet. Offset along the fault is complex but appears to decrease inland.

D-1.1.3 Hydrogeology

Groundwater flow patterns in the unconfined aquifer are complex and reflect the significant deformation of the Pleistocene sediments. The PRM-area graben and its extension to the northeast exerts significant control on groundwater flow, particularly in the western half of the project area. The graben acts as a drain to the rest of the aquifer because: 1) the aquifer within the graben has a lower base level (Cook Inlet) than the areas north and south of the graben, 2) the aquifer is thicker within the graben creating a more transmissive zone compared to the surrounding areas, and 3) the arcuate north fault is a low-flow hydraulic boundary that directs groundwater flow down the graben. As a result, most of the unconfined aquifer groundwater in the refinery area funnels into the graben and then flows southwest to enter Cook Inlet through intertidal and subtidal seeps. East of the graben and associated trough, groundwater flows south onto the refinery and then follows a roughly arcuate clockwise path through the eastern and southern part of the project area. A steep hydraulic gradient zone is present where the aquifer transitions from the dome-shaped structural high below the refinery process units to the deep synclinal trough located just to the west. Other steep gradient zones are present in the unconfined aquifer (e.g., the E-150 hydraulic barrier), but these appear to be associated with high-angle structures that create linear low-flow zones. Additional groundwater flow complexities in the unconfined aquifer occur in areas where the A-aquifer pinches out against the 60-foot clay creating local no-flow boundaries such as in the PRM and E-77 areas.

Water levels in the unconfined aquifer are between four and 40 feet higher than the pressure head in the UCA. While the head differences indicate that the main aquitard is an effective groundwater flow barrier, the head differences are probably sufficient to cause groundwater flow from the unconfined aquifer to the UCA. Other potential pathways for groundwater flow between the aquifers are the juxtaposition of the aquifers across faults and sandy interbeds within the main aquitard. Flow through these potential pathways has not been assessed.

The UCA is divided into two groundwater flow areas, the northeast and southwest regimes, which are separated by a steep-gradient zone where aquifer heads decrease by 20 to 30 feet across a narrow distance. The origin of the steep-gradient zone is uncertain but it is interpreted to follow a linear northwest – southeast trend and may be a structure similar to the E-150 hydraulic barrier in the unconfined aquifer. Groundwater flow in the northeast regime is generally to the southwest approximately perpendicular to the steep-gradient zone. Groundwater in the southwest regime flows at a uniform gradient toward Cook Inlet where it discharges predominantly through subtidal seeps.

D-1.2 REGULATED UNITS, SOLID WASTE MANAGEMENT UNITS, AND CORRECTIVE MEASURES

The CAPP is a plan for remediating soil and/or groundwater associated with releases from the three regulated units and two solid waste management unit listed on Table D-1. The CAPP contains five groundwater corrective measure (CM) systems that each address a specific plume or portion of a plume (Figure D-10). Figure D-2 is a plan map showing the locations of the active CM systems. One groundwater plume resulting from the closed surface impoundments is referred to as the SI plume and is addressed by the SI CM system. A second groundwater plume resulting from the oily water sewer system is more complex and is addressed by four CM systems: the PM, PRM, B-aquifer, and UCA systems. The PM system addresses the source area for the plume that has developed from the oily water sewer system releases in the unconfined aquifer. The PRM system operates in the downgradient portion of the same plume and is considered a separate CM for operational purposes. The source of the B-aquifer and UCA plumes (Figures D-13 and D-14, respectively) is the PM/PRM plume. These plumes occur in distinct hydrogeologic units and are addressed by separate CMs.

The groundwater CM systems employ active remediation methods to control plume migration. Tesoro anticipates that active remediation may not be needed at some point to maintain plume control and that corrective measures could incorporate monitored natural attenuation (MNA). The CAPP provides an approach for implementing and evaluating the efficacy of MNA as a sequential step in the remediation process.

Contaminated soil at the solid waste management units will be addressed after light, non-aqueous phase liquid (LNAPL) recovery has been completed. Exposure risks associated with contaminated soil will be assessed, and corrective measures will be developed if necessary to address unacceptable exposure risks.

D-1.3 TARGET ANALYTES

The *target analytes* for this CAPP include: the analytes listed in 40 CFR 264 Appendix IX (*Appendix IX analytes)*, gasoline-range organics (GRO) and diesel-range organics (DRO) as defined by the State of Alaska, and natural attenuation parameters. The following lists of analytes are subsets of this target analyte list.

Contaminants of potential concern (COPCs) are refinery-specific potential contaminants (Table D-2). This COPC list was developed from the sources listed below:

1) The Region 5 Skinner List: In 1985 the EPA Office of Solid Waste (OSW) developed the "Skinner list" of Appendix VIII hazardous constituents that are applicable to refining wastes. In 1993, OSW updated the Skinner list as a part of the EPA guidance for "Petitions to Delist Hazardous Wastes" and published this list as "Constituents of Concern for Waste from Petroleum Processes." In 1997, the Region 5 Waste Management Branch combined the 1985 and 1993 lists and published it as the Region 5 Skinner List. All of the organic constituents from this list are included as COPCs.

2) Guidance for Data Usability in Risk Assessment (EPA, 1992): Appendix II lists common pollutants associated with the refining industry. All of the organic constituents from this list are included as COPCs.

3) Tesoro groundwater monitoring data: All Appendix IX organic contaminants that have been detected in groundwater at the Tesoro refinery are included as COPCs.

4) Groundwater Metals Assessment Report (KSI, 2005): Metals that are present in Tesoro's groundwater at concentrations near or above background concentrations are included as COPCs.

Contaminants of concern (COCs) are site-specific COPC analytes that have been detected in the Tesoro refinery groundwater at concentrations greater than:

i) $1/10^{th}$ the State of Alaska Groundwater Criteria contained in Title 18 Alaska Administrative Code (AAC) Part 75 (*Alaskan criteria)*, or

ii) $1/10^{th}$ EPA's Maximum Contaminant Levels (*MCLs)* if an Alaskan criteria is not established, or

iii) $1/10^{th}$ the EPA Region IX Preliminary Remediation Goals (PRGs) or above their detection levels, whichever is greater, if neither Alaska nor MCL criteria are established.

Tesoro received an exemption from listing arsenic and lead on the COC list (KSI, 2005) even though they are present in concentrations greater than $1/10^{th}$ the State of Alaska or MCL criteria because they are present in concentrations similar to background concentrations and there is no evidence for a release of metals to groundwater. The COCs are listed on Table D-3.

EPA approves Target Groundwater Protection Standards (TGPS) for COCs as discussed in Section D-1.4. A COC review is performed once per year to ensure that the list of COCs on Table D-3 is complete. The review consists of evaluating samples analyzed for COPC analytes. A COPC is added to the COC list if a sample result exceeds $1/10^{th}$ the relevant criteria listed above. The analyte will not be added to the COC list if Tesoro can demonstrate to EPA's satisfaction that the analytical result does not represent groundwater conditions (e.g., a sampling artifact) or is below background concentrations for the analyte.

Indicator parameters are analytes that are used to monitor plume migration and degradation on a regular basis. The indicator parameters for each CM are listed on Table D-4.

Natural attenuation parameters are used to monitor the occurrence of naturally-occurring degradation processes in groundwater. The natural attenuation parameters to be monitored will be selected on a CM-specific basis. The analytes that are currently used to monitor the UCA are listed on Table D-5. This table will be revised as needed to show the monitoring parameters selected for future natural attenuation programs.

D-1.4 CLEANUP GOALS

The TGPS for the COCs are included on Table D-3 and are based on the Alaska groundwater criteria for drinking water aquifers contained in 18 AAC 75. Tesoro may propose to use the Alaska criteria for non-drinking water for the unconfined aquifer if Tesoro can fulfill the demonstration requirements contained in 18 AAC 75.350.

Soil criteria will be established at a later date as discussed in Section D-9.0.

D-1.5 GROUNDWATER CORRECTIVE MEASURE CLOSURE DEMONSTRATIONS

The CAPP requires a closure demonstration showing that each CM described in Sections D-2.0 through D-7.0 has achieved the cleanup goals identified in Section D-1.4 before the CM system can be dismantled. The closure demonstration consists of two parts, *readiness demonstrations* and *standby demonstrations.*

The *readiness demonstration* consists of five quarters of sampling while the CM is active during which all sample results must meet the cleanup goals shown on Table D-3. During quarters 1 and 5, all corrective action monitoring wells listed on Table D-8 for the closing CM must be sampled and analyzed for the COCs listed on Table D-3. During quarters 2, 3, and 4, all corrective action monitoring wells for the CM must be sampled and analyzed for the indicator parameter(s) listed on Table D-4. These data will be used for assessing cumulative risk of the mixture of COCs remaining in the groundwater using the procedures required by the State of Alaska in 18 AAC 75.325(g) and described in the State of Alaska's *Cumulative Risk Guidance,* dated November 7, 2002. Per EPA's request, methyl-tert-butyl ether (MTBE) will be included in the list of COCs used in the cumulative risk analysis for the PM, B-Aquifer, and UCA areas. QPR 38 includes a discussion of the MTBE data that have been collected to date.

The *standby demonstration* consists of putting the CM on standby mode for three years while continuing to monitor groundwater flow and quality. Tesoro will submit a CM standby plan to EPA that includes a description for how the CM will be maintained, a standby groundwater monitoring plan, and the results of the cumulative risk assessment. Tesoro will begin the standby demonstration only after EPA has approved the standby demonstration plan. Each analytical sample result obtained during the three-year standby demonstration must continue to meet the TGPS or Tesoro must complete one of the following three actions.

1) Demonstrate that the sampling result is a sampling artifact or associated with another source,
2) Return the CM to operation, or
3) Submit a revised CM standby plan that includes: a) an assessment of risk associated with the detection, b) any needed modifications to the standby monitoring plan, and c) an assessment of the need to implement additional corrective actions.

D-1.6 PERFORMANCE STANDARDS FOR THE CORRECTIVE ACTION PROGRAM

Performance demonstrations are performed semi-annually based on the quarterly monitoring data, and the specific performance demonstrations required for each CM are described in Sections D-2.0 through D-7.0. The performance of each CM system will be assessed using the following three criteria.

- *Effectiveness.* Each groundwater CM system must be operated in a manner that prevents contaminant migration beyond an extraction or in-situ treatment system.
- *Adequate progress.* Each CM system must be operated in a manner that reduces the presence of contamination in the environment at an adequate rate.
- *Protection of human health and the environment*. Each CM system must be operated in a manner that protects human health and the environment.

A *corrective action modification plan* (CAMP) will be submitted to EPA if Tesoro cannot meet one or more of the performance demonstrations. The CAMP will be implemented upon obtaining approval from the EPA.

D-1.7 TREND ANALYSES

One of the principal methods for performing the adequate progress demonstrations identified in Section D-1.6 is concentration trend analysis. The demonstration requires that the indicator parameter for a CM has either a statistically significant non-positive trend or an acceptable contaminant level for the non-trend scenario. A statistically significant positive trend requires a CAMP. The non-positive trend analysis is discussed in Section D-1.7.1 and the non-trend scenario is discussed in Section D-1.7.2.

D-1.7.1 Statistical Method for Non-Positive Trend Determination

The non-parametric Mann-Kendall test for trend (S) is used to assess the concentration trend within a single well for an indicator parameter, and the Z test statistic is calculated to test the indicator parameter trend significance at a 95 percent confidence level ($Z_{0.95}$). The indicator parameter trend for *n* data points is not significant if the absolute value of Z is less than the tabulated value of $Z_{0.95}$ for n-1 degrees of freedom. It has a negative trend if $S<0$ and $Z<-Z_{0.95}$ and a positive trend if $S>0$ and $Z>Z_{0.95}$. The trend analysis is performed semi-annually using the monitoring data set collected after a CM is implemented with a minimum number of 13 data points. If a CM is subsequently modified with a CAMP, the 13 data points after the CAMP is implemented will form the initial data set for trend analysis. Detailed procedures for these calculations are described by EPA (1996).

D-1.7.2 Acceptable Contaminant Level for the Non-Trend Scenario.

Contaminant concentrations that stabilize and result in neither a positive nor a negative trend is referred to as the non-trend scenario or the asymptote for the degradation curve. Many factors may impact the average concentration level at which the asymptote forms, including (but not limited to) the amount and type of residual LNAPL, soil types and resulting dispersion rates, water levels and groundwater flowpaths, and infiltration rates. In the event of a non-trend result, Tesoro will analyze site-specific factors affecting the level at which the asymptote occurs and assess the need for accelerated remediation. The analysis will involve an assessment of risk and cost-effectiveness of implementing additional corrective actions.

D-1.8 ORGANIZATION OF THIS DOCUMENT

Sections D-2.0 through D-6.0 of this document each describe one of the five groundwater CMs and provide the historical background of the plume's discovery, investigation and remediation; the conceptual model for contaminant migration and exposure pathways; and the CM's objectives, design, monitoring plan, and performance demonstration. Section D-7.0 describes how MNA would be implemented for individual CMs. Section D-8.0 describes corrective measures for soil. Section D-9.0 describes the QPRs that Tesoro submits to EPA. Section D-10.0 describes the Compliance Monitoring Program. Section D-11.0 provides well installation and decommissioning procedures for wells used in CM systems and in CM and compliance monitoring.

D-2.0 CLOSED SURFACE IMPOUNDMENT (SI) CORRECTIVE MEASURE

The closed surface impoundment (SI) area is located in the northeast corner of the refinery (Figure D-2) where Tesoro constructed three unlined surface impoundments. The impoundments were used primarily to dispose oily wastes generated at the refinery. Some drilling mud remnants mixed with crude oil were also placed in the surface impoundments. Tesoro discontinued using the impoundments for waste disposal in 1980 and closed the pits as described in the Part B Permit Application (Permit Attachment B).

D-2.1 CONCEPTUAL MODEL OF CONTAMINANT MIGRATION

The source of groundwater contamination in the SI area was removed by solidifying and capping the former surface impoundments as described above.

Groundwater contamination in the SI area occurs within a merged portion of the unconfined aquifer and consists primarily of dissolved-phase hydrocarbon constituents with a localized occurrence of LNAPL. Wells SMW-12A and SMW-33 are the only wells that have contained a measurable thickness of LNAPL, and it was present only sporadically. The dissolved-phase hydrocarbon plume (Figure D-10) is approximately 350 feet long and 150 feet wide based on 2016 analytical data and benzene as the indicator compound. Low concentrations of trichloroethene (TCE), vinyl chloride, and other halogenated compounds also occur at Surface Impoundments 1 and 3, and in the vicinity of the air sparge system. The geochemical conditions created by the presence of hydrocarbons at Surface Impoundment 3 appear to be conducive to reductive dechlorination of the TCE and the production of 1,2-dichloroethene and vinyl chloride as daughter products.

The hydrocarbon plume flowpaths are entirely within the groundwater air sparge line described in Section D-2.2. The groundwater plume does not extend downgradient of the hydraulic control system nor into the UCA (see Tesoro's QPRs). The TCE plume flowpaths are also within the SI treatment zone, but TCE migration beyond the air sparge line has occurred, beginning in 2011. As described in QPR16-1 Appendix C, the air sparge system will undergo optimization testing to assess its capability to remediate the groundwater plume. The corrective measures described in Section D-2.2 include options for enhanced reductive dechlorination in the event that the current CM is insufficient to achieve TCE treatment.

The unconfined aquifer is not used for drinking water below or downgradient from the refinery, and potential exposure pathways or receptor populations for groundwater have not been identified.

D-2.2 DESIGN AND OPERATION PLAN

The SI CM consists of two air sparge (AS) treatment lines plus the option for enhanced reductive dechlorination. The SI air sparge system has been operating as a supplemental treatment system since October 2005. Figure D-3 is a plan map showing the location of the system components, and Table D-6 lists the minimum operating specifications for the system. The SI sparge system lies entirely within the fenced and access-controlled portion of the refinery. Enhanced reductive dechlorination, if conducted, would also be entirely within the fenced portion of the refinery.

D-2.2.1 Air Sparge Treatment System

This section describes the mechanics of the SI AS system. As described in QPR16-1 Appendix C, an optimization evaluation will be conducted to assess the viability of the AS system for continued remediation of the groundwater plume, especially TCE. The role of the AS system in the CM will be based on the optimization evaluation. For instance, if the system is deemed capable of continued benzene treatment, but not TCE treatment, then the system would be operated in conjunction with enhanced reductive dechlorination (Section D-2.2.2).

Two in-situ AS treatment lines have been established for the system: a longer, northern AS line and a shorter, southern AS line. The AS wells are screened approximately14-feet below the water table and are constructed of two-inch diameter PVC materials with 2.5-foot screen intervals at the bottom (Figure D-4). The northern line consists of 22 sparge wells arrayed in a line along the south edge of the engineered caps over closed Surface Impoundments 1 and 2. The northern treatment wells are installed approximately 18 to 40 feet apart and create a 390-foot treatment wall that spans the SI plume width from west of well SMW-21 to SMW-07. This treatment line supplies air for stripping of volatile compounds and oxygen to support aerobic biodegradation of contaminants downgradient of the sparge zone. Five of the northern AS wells (wells SAS-16 through SAS-20) have nested injection well points that can be used to deliver chemical additives if needed.

The southern line consists of wells AS-23 through AS-25. These wells were previously operated in concert with groundwater extraction well RS-2. Neither the southern sparge wells nor RS-2 are necessary for continued operations because groundwater quality between the two sparge lines previously reached asymptotic conditions. The southern sparge wells and groundwater extraction well RS-2 are available for contingency operations if the CM upgradient is insufficient to stabilize the plume.

A 15-horsepower rotary lobe blower with an air flow capacity of approximately 140 cubic feet per minute (cfm) provides air to the system and is housed in the SI building near the sparge lines. The blower feeds air to the wells through three actuated ball valves to three distribution headers as shown on Figure D-4. Air flow to individual wells are controlled and monitored using ball valves, pressure gauges, and flow meters installed on each line.

The sparge system is operated continuously. Flow is cycled between the three well banks to provide pulsing at individual wells. The pulse schedule can be adjusted to optimize the zone of air influence within the subsurface at each well. Individual wells operate at flow rates between 5 and 15 standard cubic feet per minute (scfm). Table D-6 shows the minimum operating requirements for the AS system.

D-2.2.2 Enhanced Reductive Dechlorination

Biodegradation of TCE and its daughter products cis-1,2-DCE and vinyl chloride provides an additional mechanism for attenuation of chlorinated compounds in the SI area. Available data suggest that reductive dechlorination occurs in the vicinity of Surface Impoundment 3 (well SMW-34). The SI CM includes the option to utilize enhanced reductive dechlorination there or in other portions of the SI area in order to increase the rate of TCE attenuation.

Enhanced reductive dechlorination, if employed, will be conducted as biostimulation and/or bioaugmentation. Biostimulation will involve injection of nutrients or substrates that can act as electron donors (e.g., molasses or emulsified vegetable oil). Bioaugmentation will involve injection of microorganisms (e.g., dehalococcoides ethenogenes) capable of dechlorinating TCE and its daughter products.

Enhanced reductive dechlorination can work alone or in tandem with the air sparge system. Specifically, the air sparge system can act as a "polishing step" to decrease TCE daughter product concentrations and return groundwater to less reducing conditions.

Two steps will be required for use of enhanced bioremediation as a part of the SI CM. First, Tesoro will conduct testing on a pilot scale to assess applicability. The pilot testing will identify appropriate amendments, doses, and effects on the plume. Second, Tesoro will submit a work plan for EPA approval to conduct full scale implementation.

D-2.3 REQUIRED PERMITS

There is no required permit for the air sparge system. If enhanced reductive dechlorination is employed, Tesoro will obtain necessary permits for injection of amendments to the subsurface.

D-2.4 CORRECTIVE MEASURE MONITORING

Tesoro performs groundwater and treatment monitoring to assess the performance of the SI CM. Monitoring consists of measuring groundwater levels, collecting and analyzing groundwater samples, and maintaining treatment records. Groundwater gauging and sampling are performed in accordance with Permit Attachment C.

Water level monitoring. Tesoro gauges water and apparent LNAPL thickness in the wells listed on Table D-7 and prepares groundwater contour maps two times per year in the spring and fall quarters to assess groundwater flow directions.

Water quality monitoring. Tesoro collects groundwater samples from the wells listed on Table D-8, shown on Figure D-10, for the analyses shown on Table D-8. The objectives for this sampling are as follows:

- Samples are to be collected from wells SMW-10, SMW-31, SMW-32, and SMW-33 two times per year and analyzed for the indicator parameters (Table D-4) to monitor the performance of the northern AS treatment zone. These data will be used in the semi-annual effectiveness demonstrations discussed in Section D-2.5.
- Samples are to be collected side-gradient to the plume from well SMW-5, SMW-12B and SMW-24 two times per year for the indicator parameters (Table D-4) to monitor for plume expansion. These data will be used in the semi-annual effectiveness demonstrations discussed in Section D-2.5.
- Samples are to be collected within the plume from wells SD-3, SMW-21A, and SMW-34 two times per year for COCs (Table D-3), to monitor degradation of the plume. These data will be used in the semi-annual effectiveness and adequate progress demonstrations discussed in Section D-2.5.

- Samples are to be collected downgradient of the plume from well SMW-9 and SMW-29 two times per year and analyzed for the COCs (Table D-3). These data will be used in the annual protection of human health demonstrations discussed in Section D-2.5.
- Samples are to be collected from well SMW-I-1once per year to monitor the COPC analytes. These data will be used in the COC review discussed in Section D-1.3.

Treatment monitoring. Tesoro will record the sparge well air flow and pressure on a weekly basis as shown on Table D-10.

D-2.5 CORRECTIVE MEASURE PERFORMANCE DEMONSTRATION

Effectiveness demonstration. The effectiveness of the SI AS treatment system will be demonstrated based on the gauging and analytical sampling data described in Section D-2.4. The effectiveness of the system will be assessed two times per year. The system will be considered effective if each well that is sampled contains analytes in concentrations below the TGPS specified in the Permit or the groundwater flowpath intersects the AS treatment zone.

Adequate progress demonstration. Adequate progress in meeting the SI CM cleanup objectives will be demonstrated two times per year by showing a non-positive concentration trend in the indicator parameters (benzene and TCE) using the methods described in Section D-1.7.

Protection of human health demonstration. The ability of the SI CM to protect human health will be demonstrated once per year by showing that downgradient wells SMW-9 and SMW-10 contain the COCs in concentrations at or below the TGPS.

D-3.0 PHILLIPS MARATHON (PM) CORRECTIVE MEASURE

The Phillips-Marathon (PM) plume area underlies the Tesoro Refinery and adjacent properties currently owned by ConocoPhillips (Phillips) (Figure D-2). The plume name derives from the former ownership record. The principal source for the PM groundwater contamination is an oily water sewer system that was installed when the refinery was originally built. The oily water sewer system conveys waste hydrocarbon materials and wastewater generated in the refinery process units, bulk storage tanks, and laboratory through a network of underground steel pipes to the API separator. The system includes a series of seal boxes that provide flow control and lift stations that pump the wastewater through the piping. The original seal boxes had flush-grade entries and below-grade chambers. The below-grade chambers were constructed of three pre-cast concrete sections grouted together, and the wastewater inlet and outlet pipes were also grouted into the chamber.

Leaks around the inlet and outlet pipes and between the grouted sections of eleven seal box chambers were identified during inspections conducted during the spring of 1987. All of the seal boxes on the refinery have since been replaced with 0.50-inch thick steel chambers. The inflow and outflow pipe connections were welded into the new steel seal boxes. The new seal boxes were coated to prevent corrosion on the inside and outside using epoxies.

D-3.1 CONCEPTUAL MODEL OF CONTAMINANT MIGRATION

The PM groundwater plume occurs in the A-aquifer and merged portions of the unconfined aquifer as both LNAPL and dissolved-phase contamination (Figure D-10). The source for the contamination has been removed by replacing and modifying the seal boxes in the oily water sewer system as described above.

The groundwater plume consists of hydrocarbon contamination with no evidence for other organic or inorganic constituents. EPA requested additional data to confirm the absence of metals contamination in groundwater in the PM and PRM areas, and Tesoro submitted a report (KSI, 2005) to provide the requested information. This report confirmed the absence of a metals release to groundwater, although arsenic may be mobilized as the result of geochemical changes associated with the hydrocarbon groundwater plume.

The plume extends west from the refinery's main process area across the Kenai Spur Highway onto the Phillips' liquid natural gas (LNG) plant property where it is referred to as the PRM plume (Figure D-1). The highway forms the arbitrary west boundary of the PM plume and the east boundary of the PRM plume. The PM portion of the plume has historically been divided into four LNAPL lobes: the main PM lobe, the boardwalk lobe, the tanks 10/11 lobe, and the E-77 lobe (Figure D-10). The significance of these plume lobes has, and will continue to, diminish as the extent of LNAPL declines. However, an expansion of the plume along its northwest edge was observed in association with formation of the PM Swamp in late summer 2012. Heavy rainfall across the western Kenai Peninsula caused regional groundwater levels to rise and a former wetland to inundate and form a swamp. The PM Swamp developed, and because it was connected with the underlying aquifer, resulted in expansion of the PM Plume. Although early in the PM Swamp's history, the surface water extended past the north fault (Figure D-10), evidence of hydrocarbon transport beyond the fault line was not observed. The PM Plume expansion is expected to diminish as the Swamp footprint diminishes. Still, because heavy rainfalls may occur again in the future, the PM CM is designed to address similar future expansions of the plume.

The unconfined aquifer within the PM area is not used for drinking water and potential exposure pathways or populations have not been identified within the PM area. The PM plume is thought to also be the source for the PRM, B-aquifer, and UCA groundwater plumes. Migration pathways to and within those plumes are discussed in Sections D-4.0, -5.0, and -6.0, respectively.

D-3.2 Design and Operation Plan

The PM CM consists of groundwater extraction, treatment, re-injection of treated groundwater and the operation of the highway air sparge system. Historically, groundwater extraction has focused on the shallow part of the unconfined aquifer. With the highway air sparge and PRM air sparge (Section 4.0) systems in place, there will likely be less need for shallow groundwater extraction in the PM area in the future. The current PM CM design trend is to deepen groundwater extraction in the A-aquifer so the combination of air sparging and groundwater extraction is optimized for most efficient remediation.

D-3.2.1 Groundwater Extraction System

The PM groundwater extraction system has operated since 1991. The treatment system includes equipment in the PM Treatment Building (Figure D-5) located within the fenced and access-controlled portion of the Tesoro refinery, associated piping, wells, recharge trenches, and instrumentation located on adjacent Tesoro and ConocoPhillips properties. Figure D-5 is a plan map showing the location of the groundwater extraction CM components, and Table D-6 lists the minimum operating specifications for the system.

The PM extraction system includes 14 recovery wells (wells R-19 to 28, R-33, R-34A, R-36, and R-53) that can be operated to control groundwater flow patterns and remove dissolved hydrocarbons from the upper part of the unconfined aquifer. Because these wells are screened within shallow groundwater that is treated by the Highway AS system and the PRM AS system, the wells are offline. In addition to the 14 shallow recovery wells, recently-installed R-21R (Figure D-5) is screened within the deeper part of the unconfined aquifer. This well, and other possible deeper wells installed in the future, will allow for extraction of groundwater that is not treated by the air sparge systems. Currently only R-21R is operating in the PM groundwater extraction system. If additional wells are installed, they will be incorporated to the PM CM.

Recovered groundwater is treated at the PM Treatment Building and/or the Calgon unit. The PM treatment process is based on air stripping using tray aeration units (Figure D-6). The influent groundwater is pumped to a surge tank and then to the tray strippers. Dissolved-phase volatiles are removed from the water via atmospheric air stripping in the four tray stripper units. Water is pumped to the top of the strippers and allowed to cascade over the aeration trays while air introduced into the bottom of the strippers flows upward to volatilize hydrocarbons. The design capacity of the PM groundwater treatment system is 400 gpm if all the tray strippers operate simultaneously; however, two tray strippers typical operate at a time at 120 to 140 gpm each.

The stripper off-gases are treated in a regenerative thermal oxidizer (RTO) during normal operation. Granular activated carbon (GAC) absorbers are installed in parallel with the RTO and are used to treat stripper off gas in the event of a planned or unexpected shut-down of the RTO. The treated off-gas from either the RTO or the

GAC absorber is released to the atmosphere. The carbon filters are monitored for efficiency and replaced when saturated with hydrocarbons. The spent carbon is sent to an off-site carbon regeneration facility.

The Calgon unit treatment process is based on GAC adsorption (Figure D-7). Groundwater is pumped through two 20,000-pound GAC filters in series. The water flows through the GAC constantly. Over time, this causes an accumulation of hydrocarbons in the filter, which requires the GAC to be replaced periodically. The design capacity of the Calgon unit treatment system is 1,000 gpm, however the injection well permitted maximum (Treated Groundwater Injection Plan) is 1,000,000 gallons per day or 694 gpm. The spent Calgon carbon is sent to an off-site carbon regeneration facility.

The PM treatment system effluent is discharged to the unconfined aquifer via an equalization lagoon and infiltration trenches or it is discharged to Cook Inlet via the Tesoro refinery wastewater treatment plant. The equalization lagoon and four recharge trenches are located on Tesoro and Phillips properties south of the refinery (Figure D-2). The equalization lagoon serves as an iron precipitate settling basin. The trenches consist of distribution boxes with horizontal laterals of perforated pipe backfilled with drain rock. The drain rock is overlain by a filter fabric and surface-covered with native materials. The infiltration trenches clog during the normal course of operation and are rebuilt every one to two years. One trench is operated at a time, while the others are rebuilt or remain in standby.

The Calgon unit effluent is discharged through injection wells IR-29 through IR-32 into the lower portion of the A-aquifer. The injection wells are constructed of six-inch diameter PVC with 15-feet of 0.02-inch slotted screen interval terminating at the 60-foot clay.

The PM recovery wells and infiltration trenches have historically been operated to control lateral spreading of the LNAPL and dissolved-phase hydrocarbon plumes in the upper portion of the unconfined aquifer. With expansion of the PM CM to include the highway air sparge system, such shallow pumping may have less utility. The PM CM allows groundwater extraction to be conducted from the deeper part of the unconfined aquifer. This may be conducted with R-21R and/or additional deep wells installed in the future.

Supplemental remedial measures are operating in the PM area (KSI, 2001c) to accelerate remediation of the PM plume. The supplemental systems are not considered necessary to meeting the overall containment objective for the PM CM and therefore are not included in the PM CM.

Table D-6 shows the minimum operating requirements for the PM extraction and re-injection systems.

D-3.2.2 Highway Air Sparge System

The highway air sparge system is located on Tesoro property immediately west of the Kenai refinery (Figure D-5). Figure D-6 is a schematic process diagram for the highway AS/SVE CM, and Table D-6 lists the minimum operating specifications for the system. The system injects air to the upper part of the unconfined aquifer for stripping and enhanced aerobic biodegradation of benzene. Design air flow rate is 8 to 20 cfm per well. The system consists of 24 air sparge wells, 6 soil vapor extraction (SVE) wells, and 8 vapor monitoring points. The air sparge wells are spaced at approximate 25-foot intervals, with 2.3-ft screens placed approximately 34 feet below the water table. The SVE wells have 7- to 10-ft long screens positioned just above the water table. The vapor monitoring points have 1-ft screens within the vadose zone at least 5 feet above the water table.

The air sparge blower, SVE vacuum pump, air flow headers, and system controls are housed in an equipment connex located near the line of wells. The 15-horsepower rotary claw air sparge blower has a capacity of 150 cfm. The blower feeds air to the wells through a motorized three-way valve and distribution header as shown on Figure D-6. Air flow to individual wells is controlled and monitored using ball valves, pressure gauges, and flow meters installed on each line. The 7.5-horsepower regenerative SVE vacuum blower has a capacity of 230 cfm. The SVE blower uses a knockout vessel with a high level switch to remove liquids from the extracted gases. The SVE system includes a 1,000-pound GAC.

D-3.3 REQUIRED PERMITS

Recovery well groundwater extraction is permitted under ADNR TWUP A00-19.

Off-gas air emissions from the PM treatment systems are regulated by the ADEC Air Quality Operating Permit No. AQ0035TVP02.

Discharge of treated groundwater to the injection trenches is regulated under Tesoro's *Treated Groundwater Injection Plan* dated May 17, 2017 and approved by ADEC.

Discharge via the wastewater treatment plant and/or outfall line is permitted under Tesoro's APDES permitted wastewater treatment system (number AK0000841).

D-3.4 CORRECTIVE ACTION MONITORING

Tesoro performs groundwater and treatment monitoring to assess the performance of the PM CM. Monitoring consists of measuring groundwater and LNAPL levels, collecting and analyzing groundwater samples, and maintaining treatment records. Groundwater gauging and sampling are performed in accordance with Permit Attachment C.

Water level monitoring. Tesoro gauges water and LNAPL levels in the wells listed on Table D-7 and prepares groundwater contour maps two times per year during the spring and fall quarters to assess the effectiveness of the PM recovery wells.

Water quality monitoring. Tesoro collects groundwater samples from the wells listed on Table D-8, shown on Figure D-10, for the analyses shown on Table D-8. The objectives for these samples are as follows:

- Samples are to be collected on the south side of the plume from wells E-72RR, E-89, E-94, E-162 and E-208 two times per year and analyzed for the indicator parameter (Table D-4) to demonstrate that the plume is not expanding laterally in the area where the injection trenches provide hydraulic control of the plume. These data will be used in the semi-annual effectiveness demonstrations discussed in Section D-3.5.

- Samples are to be collected on the north side of the plume from wells MW-12, E-59, E-65R, E-92, E-93A, E-122, E-229, and E-231 two times per year and analyzed for indicator parameter (Table D-4) to demonstrate that the plume is not expanding northward. These data will be used in the semi-annual effectiveness and adequate progress demonstrations discussed in Section D-3.5.
- Samples are to be collected within the PM plume from wells E-38 and E-55 two times per year, once for COPCs (Table D-2) and once for COCs (Table D-3). The COPC data will be used in the annual COC review discussed in Section D-1.3.
- Samples are to be collected within the dissolved-phase plume from wells E-4, E-14, and E-30A two times per year for the COCs (Table D-3) to monitor plume degradation. These wells will not be sampled if LNAPL or a sheen is present at the time of sampling. These data will be used in the semi-annual effectiveness and adequate progress demonstrations discussed in Section D-3.5.
- The SVE System will be monitored as shown in Table D-9. These data will be used in the semi-annual effectiveness demonstrations discussed in Section D-3.5.

Treatment monitoring. Tesoro records the volume of groundwater treated at the PM treatment facility on a daily basis and the PM recovery well pumping rates on a weekly basis as shown on Table D-10. These volumes include groundwater recovered from the PM, and PRM areas.

D-3.5 CORRECTIVE MEASURE PERFORMANCE DEMONSTRATION

Effectiveness demonstration. Tesoro will demonstrate the effectiveness of the PM recovery system based on the gauging and analytical sampling data described in Section D-3.4. The effectiveness of the system will be assessed two times per year. The system will be considered effective if each well that is sampled contains analytes in concentrations below the TGPS or the flowpath through the well intersects the capture zone of the PM or PRM recovery wells.

Adequate progress demonstration. Adequate progress will be demonstrated by showing a non-positive concentration trend for the indicator parameter (benzene) using the methods described in Section D-1.7.

Protection of human health demonstration. Currently, downgradient water quality is controlled by the PRM CM. Protection of human health demonstrations will be developed for the PM CM after the EPA has approved closure for the PRM CM.

D-4.0 PRM CORRECTIVE MEASURE

The PRM plume is the downgradient portion of the PM plume and occurs entirely on the ConocoPhillips LNG property west of the Kenai Spur Highway (Figure D-2). The Kenai Spur Highway forms the western boundary of the PM plume and the eastern boundary of the PRM plume.

D-4.1 CONCEPTUAL MODEL OF CONTAMINANT MIGRATION

The PRM plume consists of LNAPL and associated dissolved-phase hydrocarbon contamination within the A and merged unconfined aquifers (Figure D-10) (KSI, 1997). Groundwater flowpaths are southwestward across the PRM area and are controlled by structural and stratigraphic features (KSI, 1997). Groundwater flow from a large upgradient area is directed through the PRM area by a no-flow hydraulic barrier to the northwest (the north fault) and a low-flow barrier to the southeast (the south fault) combined with the structurally down-dropped graben between the faults. The plume is present in the central and southern part of the graben and is currently remediated by a combination of PRM recovery wells and the PRM air sparge system

Westward groundwater transport in the E-150 area is constrained by a dry zone in the A-aquifer (referred to as the A-aquifer pinchout) which forces groundwater flow to the north and results from the top of the 60-foot clay being higher than the A-aquifer water levels. Westward migration is also restricted by a hydraulic barrier oriented transverse to the groundwater flow direction. The cause of the hydraulic barrier is not certain although it appears to be a high-angle, linear structure such as a fault or fracture. The difference in water levels across the barrier has been found to be between seven and nine feet.

The unconfined aquifer in the PRM area is not used; however, human exposures could potentially occur if the plume in the A-aquifer reached intertidal seeps on the Cook Inlet beach (KSI, 1997).

D-4.2 DESIGN AND OPERATION PLAN

The PRM CM consists of a hydraulic control system of pumping and injection wells installed in several phases between 1993 and 1999 and an air sparging system Tesoro installed in 2007. Figure D-8 is a plan map showing the location of the CM components, and Figure D-9 is a schematic process flow diagram for the CM.

Under ideal conditions, the air sparge system would be the only operating system in the PRM A-aquifer. The pumping system is supplemental; it allows for extraction of contaminated groundwater that would otherwise not be treated by the air sparge system. Should the air sparge system become sufficient for full plume treatment, then Tesoro will follow the 2009 PRM Air Sparge Transition Plan (KSI 2009) presented as Appendix D of the Quarter 53 report, as approved by EPA. The transition plan describes procedures and performance monitoring steps for decreasing and ultimately ceasing pumping from the PRM hydraulic control system.

D-4.2.1 PRM Air Sparge System

The PRM air sparge system consists of 27 operable wells installed in two parallel lines oriented perpendicular to the groundwater flow direction. The wells are generally spaced 12 to 20 feet apart with closer spacing used in the southern part of the well network where the aquifer is thin. The wells have 2-inch diameter blank casing with 2-ft pre-packed PVC well screens at the bottom. The pre-packed screens have a 3-inch diameter outer screen over a 2-inch inner screen, with filter pack within the annular seal. The screens are positioned 6 to 15 feet below the water table, corresponding to 46 to 53 ft bgs.

The air sparge system blowers and other equipment are housed in a connex building located northeast of containment dike area about 400 ft from the air sparge wells. Two 7.5-horsepower rotary vane blowers supply air to the wells through individually controlled and metered pipelines. The two blowers have a combined capacity of approximately 125 cfm. Individual wells are designed for injection rates of 4 to 15 cfm. The pipelines to the wells are 1.5-inch diameter high-density polyethylene pipe, run mostly underground and connected to the wells below grade. A programmable logic controller (PLC) allows for cycling between separate banks of air sparge wells.

An SVE system accompanies the PRM air sparge line. The SVE components include five 4-inch diameter wells previously used for groundwater injection, and one additional 2-inch well. The SVE well screens are 0.02-inch slotted PVC and extend 14 to 27 ft above the water table and are connected by piping runs to a header within the PRM air sparge connex building. Other components of the SVE system within a second connex housing the groundwater recovery manifold and controllers include vacuum gauges and control valves for each well, a water knockout vessel, a vacuum pump, sample ports, and a vapor-phase carbon vessel for off-gas treatment. The SVE vacuum pump is a 10-horse power regenerative blower with a capacity of approximately 315 cfm. The vacuum pump exhausts outside the connex through a 4-inch steel pipe.

D-4.2.2 PRM Hydraulic Control System

The hydraulic control system captures the PRM plume by using groundwater extraction. Treatment of the groundwater recovered in the PRM area is included in the PM CM. The extraction and injection wells and control systems are located entirely within the fenced and controlled-access portion of the ConocoPhillips LNG plant. Recovered groundwater is transported to the PM treatment building or Calgon GAC via pipelines that run aboveground except at road crossings where they run below ground.

Eight A-aquifer recovery wells are operable in the PRM area (R-40, R-41, R-44, R-45, R-46, R-47, R-48, and R-49). The pumps are operated continuously at rates required to completely capture the upgradient dissolved-phase plume in the A-aquifer. These wells are capable of extracting groundwater at individual rates up to 60 gpm (e.g., R-40) as needed for additional plume control.

Recovered PRM groundwater is treated at the Calgon unit by GAC adsorption and reinjected through wells IR-29 through IR-32, as described in Section 3.2.1.

Table D-6 shows the minimum operating conditions for the PRM hydraulic control system. Pumping is required until the air sparging system is fully capable of treating the plume (2009 PRM Air Sparge Transition Plan [KSI 2009]).

D-4.3 REQUIRED PERMITS

Pumping from the unconfined aquifer recovery wells is permitted under ADNR TWP 95-15, and pumping from the UCA at wells TW-5 and TW-5A is permitted under TWUP A00-19.

D-4.4 CORRECTIVE ACTION MONITORING

Tesoro performs groundwater monitoring to assess the performance of the PRM CM. Monitoring consists of measuring groundwater and LNAPL levels and collecting and analyzing groundwater samples. Groundwater gauging and sampling are performed in accordance with Permit Attachment C.

Water level monitoring. Tesoro gauges water and LNAPL levels in the wells listed on Table D-7 and prepares groundwater contour maps two times per year during the spring and fall quarters to assess the extent of capture by the PRM recovery wells.

Water quality monitoring. Tesoro collects groundwater samples from the wells listed on Table D-8, shown on Figure D-10 for the analyses shown on Table D-8. The objectives for these samples are as follows:

- Samples are to be collected downgradient of the E-150 plume from well E-168 two times per year for COCs (Table D-3) to monitor the effectiveness of the CM system. These data will be used in the semi-annual effectiveness demonstrations and the annual downgradient compliance demonstration discussed in Section D-4.5.
- Samples are to be collected downgradient from the southern PRM recovery wells from well E-171 two times per year for the COCs (Table D-3) to monitor the effectiveness of the recovery system and degradation of the plume. These data will be used in the semi-annual effectiveness and adequate progress demonstrations discussed in Section D-4.5.
- Samples are to be collected north and south of the plume from wells E-105, E-132, E-141, E-144, E-151, E-152, E-190A, E-203, and E-244 and analyzed for the indicator parameter (Table D-4) two times per year to demonstrate that the plume is not expanding laterally. These data will be used in the semi-annual effectiveness demonstrations discussed in Section D-4.5.
- Samples are to be collected within the plume from wells E-80, E-91, E-118, and E-150 two times per year to monitor plume degradation for the COCs (Table D-3). These wells will not be sampled if LNAPL or sheens are present at the time of sampling. These data will be used in the semi-annual effectiveness and adequate progress demonstrations discussed in Section D-4.5.
- The SVE system will be monitoring as shown in Table D-9. These data will used in the semi-annual effectiveness and adequate progress demonstrations discussed in Section D-4.5.

Treatment monitoring. Tesoro records the volume of groundwater treated from the PRM area as part of the PM treatment monitoring (see Section D-3.4). Recovery well pumping rates and injection well injection rates are recorded on a weekly basis and at the time of gauging (Table D-10).

D-4.5 CORRECTIVE MEASURE PERFORMANCE DEMONSTRATION

Effectiveness demonstration. Tesoro will demonstrate the effectiveness of the PRM CM based on the gauging and analytical sampling data described in Section D-4.4. The effectiveness of the system will be assessed two times per year. The system will be considered effective if each well that is sampled contains analytes in concentrations below the TGPS or the flowpath through the well intersects the capture zone of the PRM recovery wells or the treatment zone PRM air sparging system.

Adequate progress demonstration. Adequate progress demonstrations will be performed two times per year. The demonstration will consist of showing a non-positive concentration trend in the indicator parameter (Table D-4) using the methods described in Section D-1.7.

Protection of human health demonstration. The ability of the PRM CM to protect human health will be demonstrated once per year by showing that downgradient well E-168 contains the COCs (Table D-3) in concentrations at or below the TGPS.

D-5.0 B-AQUIFER CORRECTIVE MEASURE

The B-aquifer plume is dissolved-phase contamination that occurs in the B-aquifer and lower portion of the merged unconfined aquifer in the PM and PRM areas (Figure D-13). The B-aquifer contamination is distinct from the PM/PRM plume because the upgradient portions contain relatively high benzene concentrations, and the downgradient portions contain only benzene rather than all of the benzene, toluene, ethylbenzene, and xylenes (BTEX) constituents or other hydrocarbon compounds.

The wharf lobe plume previously occurred on the ConocoPhillips LNG plant (Figure D-2) and was a portion of the PRM plume that occurred within the B-aquifer. The wharf lobe plume previously had its own associated CM. Given the demonstrated improved conditions during the previous permit cycle, the monitoring for this area is included here within the broader B-aquifer CM. The wharf lobe compliance monitoring well E-160 is now included in the B-aquifer corrective action monitoring well list.

D-5.1 CONCEPTUAL MODEL OF CONTAMINANT MIGRATION

The source of the B-aquifer plume is the PM plume. Dissolved-phase hydrocarbons migrate to the lower part of the merged unconfined aquifer and B-aquifer because of stratigraphic and structural relationships near two or more separate source areas. One source area is located in the lower tank farm (west of the refinery process area) and the second source area is located near tank 65; the contamination from the two source areas merges near the western refinery boundary. The presence of benzene as the only contaminant in the downgradient portion of the plume probably results from the recalcitrance of benzene to anaerobic biodegradation combined with its greater mobility compared to other hydrocarbon compounds.

The B-aquifer in the PRM area is not used; however, temporary and incidental human exposures could potentially occur if the plume in the B-aquifer reached intertidal or subtidal seeps in Cook Inlet (KSI, 1997). Previous investigations show that the B-aquifer downgradient of the plume discharges predominantly subtidally to Cook Inlet (KSI, 2001a) which minimizes potential human exposures.

D-5.2 DESIGN AND OPERATING PLAN

The objective of the B-aquifer corrective measure (CM) is to prevent contaminant discharge to Cook Inlet by capturing and maintaining hydraulic control of the B-aquifer plume without degrading the ability of the PRM corrective measure to capture the A-aquifer plume. B-aquifer remediation began operation with three wells on an interim basis on February 8, 2001 (KSI, 2001d), with additional wells installed and the original wells replaced since then. The CM currently consists of six recovery wells, four injection wells located downgradient of the recovery wells, and a UCA production well that supplies injection water. The extracted B-aquifer groundwater is carried in a pipeline separate from the recovered PRM water pipeline to the east side of the Spur Highway where it is routed to the PM treatment system or to a GAC treatment unit. Figure D-11 shows the well locations and piping layout of the system.

The CM recovery and injection wells are operated to create a capture zone covering the B-aquifer plume width. The wells operate at between 10 and 60 gallons per minute (gpm), and the total pumping rate is between 60 and 130 gpm depending on regional water levels and the B-aquifer injection rate. The injection wells operate at 5 to 40 gpm with a total injection rate of 30 to 100 gpm. Injection water is obtained from wells TW-5 and TW-5A. Injection facilitates capture by decreasing the hydraulic gradient west of the recovery wells. Injection and pumping rates can be set to extend the capture zone west to the line of injection wells.

The B-aquifer contaminant plume may be amenable to enhanced bioremediation through injection of amendments such as nutrients, oxygen, or sulfate. Enhanced bioremediation might be used in conjunction with the existing groundwater recovery and injection system, or if of sufficient capacity, may be used instead of these actions. Two steps will be required for use of enhanced bioremediation as a part of the B-aquifer CM. First, Tesoro will conduct testing on a pilot scale to assess applicability. The pilot testing will identify appropriate amendments, doses, and effects on the contaminant plume. Second, Tesoro will submit a work plan for EPA approval to conduct full scale implementation.

Table D-6 shows the minimum operating requirements for the B-aquifer hydraulic control system.

D-5.3 REQUIRED PERMITS

Permits other than those in effect for the PRM and PM CMs are not required for the B-aquifer CM. The B-aquifer injection wells are inventoried under the EPA Region 10 Underground Injection Control program.

D-5.4 CORRECTIVE ACTION MONITORING

Tesoro will monitor B-aquifer water levels and plume concentrations to assess the performance of the CM. Groundwater gauging and sampling will be performed in accordance with Permit Attachment C.

Water level monitoring. Tesoro gauges water and LNAPL levels in the wells listed on Table D-7 and prepares groundwater contour maps two times per year during the spring and fall quarters to assess the capture zone and groundwater flow patterns in the B-aquifer.

Water quality monitoring. Tesoro collects groundwater samples from the wells listed on Table D-8, shown on Figure D-13, for the analyses shown on Table D-8. The objectives for these samples are as follows

- Samples are to be collected from downgradient wells E-160, E-163 and E-196R two times per year for COCs (Table D-3). These data will be used to monitor plume migration and to perform the annual downgradient performance demonstration.
- Samples are to be collected two times per year from well E-187B for the indicator parameter (Table D-4) to monitor plume migration.
- Samples are to be collected north and south of the plume from wells E-179, E-206, E-209, E-217B, E-224, E-233, E-245B, and E-251B and analyzed for the indicator parameter (Table D-4) two times per year to monitor lateral expansion of the plume.
- Samples are to be collected from within the plume at wells E-197, E-207, E-216, and E-234B two times per year and analyzed for the indicator parameter (Table D-4) to monitor plume degradation.

- Samples are to be collected from within the plume at well E-146 two times per year, once for analysis of COCs (Table D-3) and once for COPCs (Table D-2). These data will be used to monitor plume degradation and to perform the annual COC review discussed in Section D-1.3.
- Samples are to be collected within the plume from wells E-177B and E-215 two times per year for the COCs (Table D-3) to monitor plume degradation.

Treatment monitoring. Tesoro will record the volume of recovered groundwater from the B-aquifer. Recovery well pumping rates and injection well injection rates are recorded on a weekly basis and at the time of gauging (Table D-10).

D-5.5 Corrective Measure Performance Demonstration

Effectiveness demonstration. Tesoro will demonstrate the effectiveness of the B-aquifer CM based on the gauging and analytical sampling data described in Section D-6.4. The effectiveness of the system will be assessed two times per year. The system will be considered effective if each well that is sampled contains analytes in concentrations below the TGPS or the flowpath through the well intersects the capture zone of the B-aquifer recovery wells.

Adequate progress demonstration. Adequate progress demonstrations will be performed two times per year after LNAPL recovery is complete in the PM area (the B-aquifer plume source area). The demonstration will consist of showing a non-positive concentration trend in the indicator parameter using the methods described in Section D-1.7.

Protection of human health demonstration. The ability of the B-aquifer CM to protect human health will be demonstrated once per year by showing that downgradient well E-163 contains the COCs in concentrations at or below the TGPS.

D-6.0 UPPER CONFINED AQUIFER (UCA) CORRECTIVE MEASURE

The UCA plume underlies the refinery and adjacent properties owned by Phillips and Agrium. The source for the UCA contamination is the PM plume.

D-6.1 Conceptual Model of Contaminant Migration

The UCA contamination consists of dissolved-phase hydrocarbons. The plume is approximately 2,000 feet long and 600 feet wide (Figure D-14). The migration pathways from the PM plume in the unconfined aquifer to the UCA are uncertain although a faulty seal in Tesoro production well T-2 is a likely source for a portion of the contamination. This well was abandoned and replaced by well T-2A in 1994 to eliminate this pathway (Dames & Moore, 1996). Well T-2A was replaced by T-2B in 2013 after fouling slowed T-2A production. The UCA plume is more extensive than can be explained by this single source, however, and much of the groundwater contamination is thought to have migrated into the UCA by way of stratigraphic or structural conduits that allow direct communication between the unconfined and confined aquifers (KSI, 2000). Contaminant migration through the main aquitard may also occur in areas where large head differences exist between the unconfined and confined aquifers as suggested by hydrocarbon-impacted soil recently identified in the main aquitard (KSI, 2001c). BTEX concentrations in the UCA are stable or declining which suggests that contaminant migration rates into the UCA have decreased and that natural attenuation processes are sufficient to address the contamination.

Groundwater in the impacted portion of the UCA is produced by Tesoro for industrial use. Tesoro primarily uses the water for boiler feed, cooling tower makeup, crude oil desalting, and other production processes. Hydrocarbon compounds in process water and boiler feed are volatilized and discharged to the atmosphere, mixed with the process stream, or discharged to plant water treatment systems.

ConocoPhillips produces groundwater for cooling tower and potable water uses from well PW-3 located south of the UCA plume area. Well PW-3 is screened at the bottom of the UCA and within water-bearing zones in the lower aquitard which have not been impacted by the hydrocarbon plume (KSI, 2000). Well PW-3 has little or no impact on groundwater flow in the upper portion of the UCA that contains the dissolved-phase plume.

D-6.2 Design and Operation Plan

The UCA CM consists of monitored natural attenuation. Most of the UCA hydrocarbon plume is captured by production pumping from Tesoro well T-2B, but this is not necessarily for plume treatment. Production well T-2B is within Tesoro's locked and access-controlled facility. Figure D-14 is a plan map showing the location of the UCA production well.

The pump in well T-2B is controlled with an on/off tank level controller and runs 80 to 90 percent of the time at a constant rate of approximately 385 gpm during normal refinery operations. The time-averaged pumping rate is approximately 310 to 345 gpm and the average cycle times are approximately five to six hours on and one hour off. On an annual basis, the average pumping rate for well T-2B is between ~300 and 400 gpm.

Production pumping has been on-going since the late 1960s and is anticipated to continue while the Tesoro refinery remains in operation. In the event that the water supply well is shut down or significantly reduced in average production, Tesoro will evaluate the impact of the change on the UCA plume and submit a request for permit modification if needed.

Summary of water usage for previous five years

	T-2B*		Recovery Wells**	
Year	MGD	GPM	MGD	GPM
2012	--	--	.122	84
2013	.500	347	.110	76
2014	.500	347	.152	106
2015	.500	347	.110	77
2016	.500	347	.119	82

* estimated annual average flow rate
** all recovery wells combined
-- not measured
MGD million gallons per day
GPM gallons per minute

Migration of the UCA plume is controlled by natural attenuation processes. The efficacy of natural attenuation is demonstrated by: 1) the long-term absence of benzene exceeding the TGPS in downgradient monitoring wells, 2) decreasing contaminant concentrations in the production wells and most monitoring wells, and 3) spatial geochemical trends indicative of anaerobic microbial hydrocarbon degradation (KSI, 2000a, KSI, 2001e). The expressed assimilative capacity of the UCA is conservatively estimated to be approximately 5,000 to 11,000 micrograms per liter (μg/L) as benzene. For comparison, the maximum Quarter-80 benzene concentration in the UCA was 180 μg/L.

D-6.3 REQUIRED PERMITS

Industrial pumping in the UCA is performed under Tesoro permit ADL 42906-C Amended. Additional permits are not required for the UCA CM.

D-6.4 CORRECTIVE ACTION MONITORING

Tesoro performs monitoring to assess the performance of the UCA CM. Monitoring consists of measuring groundwater levels, collecting and analyzing groundwater samples, and maintaining pumping records. Groundwater gauging and sampling are performed in accordance with Permit Attachment C.

Water level monitoring. Tesoro gauges water levels in the wells listed on Table D-7 and prepares groundwater contour maps two times per year during the spring and fall quarters to assess the extent of capture by the production wells.

Water quality monitoring. Tesoro collects groundwater samples from the wells listed on Table D-8, shown on Figure D-14, for the analyses listed on Table D-8. The objectives for the samples are as follows:

- Samples are collected downgradient of the plume from well E-147 and analyzed for COCs two times per year to monitor the effectiveness of plume capture and control and to conduct the semi-annual protection of human health demonstration discussed in Section D-7.5.

- Samples are collected north and south of the plume from wells E-110, E-125, E-148, E-153, and E-199 and analyzed for the indicator parameter (Table D-4) two times per year to demonstrate that the plume is not expanding laterally. These data are used in the semi-annual effectiveness demonstrations discussed in Section D-7.5.
- Samples are collected within the plume from wells E-127 and E-198 two times per year for COCs (Table D-3) to monitor plume degradation. These data are used in the semi-annual effectiveness and adequate progress demonstrations discussed in Section D-7.5.
- Samples are collected from the industrial production wells T-2B and analyzed for the indicator parameter (Table D-4) two times per year to monitor the industrial water supply.
- Samples are collected upgradient of the UCA plume from well E-153 and within the plume from wells E-109, E-125, E-127, and analyzed for natural attenuation parameters (Table D-5) once per year to assess the assimilative capacity of the UCA. These data are used in the semi-annual effectiveness demonstrations discussed in Section D-7.5.
- Samples are collected within the upgradient portion of the plume from well E-109 once per year to assess all COPCs (Table D-2) and once for COCs (Table D-3). These data are used in the annual COC review discussed in Section D-1.3.

Treatment monitoring. Tesoro will monitor water levels in wells E-154 and E-200 during gauging events to assess the effects of pumping on water levels (Table D-10).

D-6.5 CORRECTIVE MEASURE PERFORMANCE DEMONSTRATION

Effectiveness demonstration. Tesoro will demonstrate the performance of the UCA CM based on the gauging and analytical sampling data described in Section D-7.4. The effectiveness of the system will be assessed two times per year. The system will be considered effective as long as the TGPS are met in downgradient compliance well E-147 and each well that is sampled either: 1) contains benzene concentrations below the TGPS, 2) the flowpath away from the well intersects the capture zone of the industrial pumping wells, or 3) expressed assimilative capacity of the aquifer exceeds the benzene concentration in the well by at least a factor of two. Tesoro will calculate the assimilative capacity of the upgradient portion of the plume based on methanogenesis as the primary process using sampling results from wells E-109 and SMW-15 and the assimilative capacity of the downgradient portion of the plume using sampling results from well E-199 based on sulfate reduction (KSI, 2000a). The assimilative capacities will be calculated as follows.

Methane: $AC_{CH4} = MR_{CH4} \,\&\, [C_{CH4(E\text{-}109)} - C_{CH4(E\text{-}154)}]$

Sulfate: $AC_{SO4} = MR_{SO4} \,\&\, [C_{SO4(E\text{-}153)} - C_{SO4(E\text{-}199)}]$

where:

AC = *Assimilative capacity*
MR_{CH4} = *Stoichiometric ratio of benzene degraded to methane produced = 1.25*
MR_{SO4} = *Stoichiometric ratio of benzene degraded to sulfate depleted = 0.22*
C = *Concentration in* $\mu g/L$.

Adequate progress demonstration. Adequate progress will be demonstrated two times per year by showing a non-positive concentration trend in the indicator parameter (Table D-4) using the methods described in Section D-1.7.

Protection of human health demonstration. The ability of the UCA CM to protect human health will be demonstrated once per year by showing that downgradient well E-147 contains the COCs in concentrations at or below the TGPS.

D-7.0 MONITORED NATURAL ATTENUATION (MNA) IMPLEMENTATION PLAN

The combined effects of active remediation and natural attenuation in each CM are anticipated to eventually achieve groundwater contaminant concentrations that can be controlled solely by natural attenuation processes. Continued operation of the active remediation system beyond this point of time may have limited impact on the CM progress. In this event, Tesoro may request agency approval to shut down the active remediation portion of a CM and monitor ongoing natural attenuation until the closure requirements are achieved.

This plan outlines the general steps for evaluating, implementing, and demonstrating the efficacy of MNA. Given the broad time span over which MNA could be implemented in the separate CMs, the specific evaluation and monitoring approach will be based on industry standard practices current at the time the request to implement MNA is made.

Implementation of MNA will proceed as follows.

1) *Characterize natural attenuation processes*. A characterization study will be performed to determine if natural attenuation processes will adequately control the plume after the active remediation system is shut off. In addition, the study will compare the rate of cleanup by MNA with continued active remediation. The study will be performed in accordance with an EPA-approved workplan using an industry-standard protocol. The work will include an investigation to identify the active microbial degradation processes and to estimate the total assimilative capacity of the degradation processes. The investigation will also address dilution and dispersion processes as needed to adequately describe attenuation processes within the plume. If applicable, the impact of shutting off the active remediation system on plume migration may be simulated by numerical modeling.

2) *Develop validation monitoring plan*. The CM monitoring plan will be revised as a validation monitoring program that can confirm the efficacy of natural attenuation over time. A long-term monitoring program will be implemented after successfully demonstrating the efficacy of natural attenuation.

3) *Develop remediation system operational readiness plan*. A plan will be developed for placing the active remediation system in standby mode. The plan will describe shutdown measures, inspection and maintenance procedures, startup procedures including provisions for startup in cold weather, and procedures for conducting twice-yearly, three-day readiness demonstrations.

4) *Initiate MNA program*. Tesoro will shut down the active remediation system and implement the validation monitoring program and operational readiness plan upon receiving EPA approval of the characterization study and implementation plans.

D-8.0 SOIL CORRECTIVE MEASURES

Four significant releases at the Tesoro refinery have been identified: JP-4 spill near Tank 40, Tank 04A spill, pipeline valve control box, and the oily water sewer system junction box releases. These releases have produced contamination in the unsaturated (vadose) zone soils at depth. Both ex-situ and in-situ soil treatment technologies have been identified, screened, and evaluated (Dames & Moore, 1993). The principal soil remediation technologies evaluated include capping, soil vapor extraction, excavation and disposal, biotreatment, and bioventing.

Unsaturated soil contamination will be addressed before the groundwater closure demonstration, required by Permit condition III.F, is approved by EPA. At that time, human exposure risks and State of Alaska cleanup criteria will be assessed and a workplan will be prepared to address soil contamination.

D-9.0 PROGRESS REPORTS

Tesoro will submit QPRs to EPA that include the following minimum information in each report:

- Each quarter's system data

Well installations/decommissions performed during the quarter. The spring and fall reports also include the following information:

- A summary of corrective actions, including changes to the CMs and new investigations.
- Groundwater and LNAPL gauging data
- Semi-annual groundwater contour maps for the merged unconfined aquifer, A-aquifer, B-aquifer, and UCA
- Semi-annual effectiveness demonstrations.

The reports will be submitted quarterly on the following schedule:

QUARTER	SUBMITTAL DATE
(1) Winter quarter (*November, December, January*)	February 28/29
(2) Spring quarter (*February, March, April*)	May 31
(3) Summer quarter (*May, June, July*)	August 31
(4) Fall quarter (*August, September, October*)	November 30

D-10.0 COMPLIANCE MONITORING

Compliance monitoring will be performed as required after each CM has met the closure criteria in the Permit. Compliance monitoring will consist of measuring groundwater levels and collecting and analyzing groundwater samples. The compliance wells for each CM are shown on the CM's plan map and listed on Tables D-7 and D-8.

Groundwater will be gauged in each well shown as a compliance well on Table D-7 on a bi-annual basis and groundwater contour maps will be prepared to assess groundwater flow directions and velocity.

Samples will be collected from each well listed on Table D-8. The samples will be collected from each compliance well two times per year and analyzed as for COCs.

Compliance reports will be submitted two times per year to provide the data collected during compliance monitoring.

D-11.0 WELL CONSTRUCTION, DECOMMISSIONING, AND MAINTENANCE

This section provides procedures for installing, decommissioning, and maintaining monitoring and CM wells.

D-11.1 WELL CONSTRUCTION AND LOGGING

The construction of any new or replacement well will be consistent with the minimum requirements established by the State of Alaska (ADEC, 2013). The installation activities will be supervised by a competent geologist, soil scientist, or engineer who will maintain a detailed geologic log of the well unless detailed information is available from another nearby well (for example, piezometers adjacent to recovery wells). At a minimum, the following information will be recorded:

- Date and time of construction
- Drilling method and any fluid used
- Borehole diameter and well casing diameter
- Well depth
- Drilling and lithologic logs
- Casing materials
- Screen material and design
- Casing and screen joint type
- Filter pack material
- Surface seal material
- Well development procedures
- Well location (surveyed to within 0.5 feet)
- Ground surface elevation to within 0.1 foot
- Top of casing elevation to within 0.01 foot
- Detailed drawing of well including dimensions.

D-11.2 WELL DECOMMISSIONING

Tesoro will notify EPA before it replaces any well that is used in a CM system or for CM monitoring or compliance monitoring purposes and provide a rationale for the decision to replace the well. The replacement well will be installed using the procedures in Section D-12.1 in a location that is as close as practicable to the well being replaced unless EPA approves a justification for another location. If the well being replaced is defective, Tesoro will close the well within 90 days after the replacement well has been constructed; otherwise Tesoro will close the well at its convenience. Well abandonment procedures will be consistent with the requirements of ADEC (2013) and will be adequate to prevent infiltration of water along the abandoned borehole.

D-11.3 REPORTING

The installation or decommissioning of a well will be reported in the next progress report following its completion unless an extension is approved by EPA.

A well installation report will include the information listed in Section D-12.1, the boring log, well as-built diagram, and a map showing the location of the well. A well decommissioning report will describe the procedures and materials used to close the well. In addition the appropriate permit figure will be updated with the new well's location or removal of the old well and submitted with the well installation or decommissioning report.

D-11.4 WELL MAINTENANCE

Wells that are part of a CM or used for CM or compliance monitoring will be maintained using the procedures described in Section B-7.2.3.3 in Permit Attachment B.

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D-12.0 REFERENCES

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